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INVITED PAPER

THE ULTRA HIGH PRECISION STEREOCOMPARATOR

By

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[redacted]

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THE ULTRA HIGH PRECISION STEREOCOMPARATOR *

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ABSTRACT

This paper describes a new photogrammetric instrument used for the precise measurement and viewing of stereo imagery.

The state of the art has been materially advanced by the provision of automatic correlation of the imagery into a stereo pair of views.

The instrument substantially assists the operator in producing an accurate and high volume of measurements particularly under conditions where the operator is scanning or changing the field of view.

The automatic operation is performed with a computer programmed for the geometry of the photographic system in conjunction with an electro-optical scanning correlation device.

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THE ULTRA HIGH PRECISION STEREOCOMPARATOR

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PREFACE

This paper describes an instrument developed by the [redacted] STAT

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The instrument is known as the Ultra High Precision Stereocomparator, and is a microscope type measuring device controlled by a computer and photoelectric scanning.

The measuring is performed by determining the x-y positions of each of two stages through the use of laser interferometers.

The measurements relate to a stereo pair of photographs, as an example, where a pair of illuminated reticle spots create a floating reference spot for x-y-z mensuration.

The instrument further advances the science of photogrammetry and it is interesting to review the historical background of the Stereocomparator.

HISTORICAL DEVELOPMENT

The Ultra High Precision Stereocomparator was made possible only through the long term developments of analytical photogrammetry and by the evolution of the high-speed electronic computer.

In trying to trace backwards through history the developments that contributed significantly to our Stereocomparator, one is impressed by the fact that there is really no starting place from which it can be said that an idea germinated and grew into the Stereocomparator. We are thus faced with an arbitrary decision as we go backwards in time to stop at some point from which we can, by stretching our imaginations, say that without this particular concept, the Stereocomparator as we know it, would never have been produced.

One convenient stopping point in our historical research is when, in our early literature, we find inquiring minds probing the whys and wherefores of perspective in the arts of drawing and painting. We are going to ascribe to Leonardo da Vinci the first concepts which led to our Stereocomparator.

Prior to the year 1500, Leonardo da Vinci and other artists were much concerned with questions and problems of perspective as applied to painting and drawing on a flat surface. This resulted in the publishing and dissemination of various conclusions and thoughts concerning graphical perspective.

These ideas of the artists were taken up by professional mathematicians of the time, and the concepts of projective geometry resulted. Projective geometry is, of course, the basis for photogrammetry. For the next 400 years, much time and effort was expended on the analytical solution of the geometrical problems that had been recognized.

Additionally, the development of the Stereocomparator is an offshoot of a parlor pastime of some 136 years ago. In 1832, Sir Charles Wheatstone invented a device that he called a stereoscope. This instrument showed a pair of views, such as portraits, seen from two different aspects which simulated the left and right eye view. The device had a definite scientific interest, and Sir David Brewster presented papers about it in 1843 and 1844 to the Royal Society of Edinburgh. The optical concepts of this simple device established the principles of stereo viewing, essential to the Stereocomparator.

During 1900 and for a several year period, Sebastian Finsterwaller began to apply analytical mathematical principles to mapping from aerial photographs.

Unfortunately for the workers in this field, the electronic computer had not been developed, and the mathematical concepts that were employed were based on the performance abilities of the laborious hand-computing techniques then available.

Paralleling the development of the analytical techniques, the practical course of photogrammetry continued through the use of specially designed instruments which performed many of the laborious hand calculations by opto-mechanical means.

The origin of the modern mathematical solution of the problems of analytical photogrammetry occur in a 15-year period, beginning in about 1934, with the publications of Earl Church. Professor Church was still limited by desk-calculator techniques, but nevertheless he was able to put the complex mathematical concepts into manageable units for solution.

By 1960, Hellmut Schmid had developed the analytical procedures from the vector notation to the matrix notation with direct application to the high speed electronic computers. Since this date, many workers have contributed significantly to the classification, expansion of detail, and the improvement of computer programs which will provide analytical computations of the highest accuracy.

The concept of our Stereocomparator utilizes the direct application of these analytical methods to the computer control of the optical viewing system without the necessity for recourse to the older instrumented opto-mechanical method of solution for the photogrammetric equations.

We have established from the mathematical concepts of the Stereocomparator that we can employ an automatically controlled variable optical system to maintain stereo viewing of non-ideal stereo pair imagery.

The Stereocomparator has thus uniquely solved the critical problem of providing mensuration accuracy of the highest order to accommodate the developing needs of photogrammetric science.

THE STEREOCOMPARATOR SYSTEM

The Stereocomparator device is actually a system made up of a series of complex subsystems. The Stereocomparator instrument itself, with its moveable stages, adjustable optics and binocular viewing eyepieces, is the heart of the installation. The necessary servos and operator controls and the measuring systems are contained in seven electronic racks, an operator control console, and pneumatic and air control system rack.

The viewing optical system consists of the following major subassemblies:

The Illumination System.
The Objective System.
The Reticle Spot Projection System.
The Zoom Magnification System.
The Anamorph System.
The Image Rotating System.
The Eyepiece Switching System.

In addition, there is a phototube scanning or image analysis system and a photoelectric light intensity control system. The optical systems, related to the image dissector tube for the image analysis system and the photo-multiplier tube for the light intensity control system, are relatively minor.

The Illumination System

The illumination source is a 450 watt xenon compact arc lamp. The condenser and projection system associated with the light source must maintain the proper optical relationship for the appropriate settings of the variable objective and zoom system.

In order to accommodate the two switching positions of the objective lenses, there are two sets of switching lenses and one set of switching fixed diaphragms. These devices switch automatically by means of electronic servos, when the objective lenses are switched. Mechanical stops are provided so that the terminal locations for the switchable elements are accurately positioned. This is because of the necessity of obtaining close optical alignment through the entire optical system.

In order to accommodate to different positions of the zoom lens system, a variable diaphragm is provided in the illumination system and the final condensing lens assembly is made adjustable. These systems are controlled by electronic servos from the zoom lens system in the main optical path. By this means, the light source arc is brought to a focus as required beneath the film plane.

Objective Lens System

Two objective lenses are provided: one with a focal length of 40mm and the other with a focal length of 80mm. These lenses are required to accommodate the continuously variable 10:1 magnification range system to provide an overall magnification range of 20:1. Thus the two objective lenses, as they are switched in or out of the system, represent a change in the magnification of the system of 2:1.

The eyepieces are of a fixed 10:1 magnification, and taking into account the zoom magnification range, the overall magnification for the instrument is 10X to 200X.

The objective lenses are controlled by an electronic system which drives a motor, which in turn drives a Geneva mechanism. The purpose of the Geneva mechanism is to position the objective lenses as accurately as possible on the optical axis. To maintain this position as closely as possible during focussing of the objective lenses, a unique system is provided which preloads the lens elements in the lens barrel, sideways to the barrel, in such a manner that there is no sideplay as the lens elements are aligned vertically during the focussing operation.

In addition, the Geneva mechanism is latched into its two terminal positions where the 40mm and the 80mm lenses are in their use positions. This latch arrangement consists of a lever arm with a tapered wedge-shaped head which falls into a tapered socket, locking the entire Geneva mechanism against rotation. The action of the Geneva drive includes unlatching the locking mechanism prior to rotation of the Geneva cams, and then relocking by inserting the tapered latch device after the Geneva drive has reached its new position.

The Reticle Spot Projection System

Immediately adjacent to the objective lenses is a beamsplitter which provides for the injection of the reticle spot into the main light path. The beamsplitter is located as close as possible to the objective lenses, since position measurements of the stages are made with respect to the reticle spot. Thus the further the reticle spot injection beamsplitter is from the film plane, the greater the potential deviation of measurement error will be. Further, the reticle spot must be injected prior to the zoom lens, anamorph lens, image rotator, etc., in the main optical path, since any eccentricity of the optical axis, as these subsidiary elements are adjusted, would result in a movement of the reticle spot with respect to the film plane and thus create a measurement error.

The reticle optical system essentially duplicates the entire adjustable optical features of the main optical path. In addition, there are added optical features required by the necessity for adjustment of the reticle size with respect to the field of view.

The reticle spot itself is a bright illuminated disc in the center of the field of view of the eyepiece. The illumination system consists of a high pressure xenon enclosed arc lamp supplying light to an aperture in a diaphragm, by means of an array of optical condensers.

The size of the aperture is so arranged that at the end of the reticle projection system the size of the reticle spot is approximately diffraction limited. The reticle spot is thus of minimum optically practical size to provide a clearly defined disc.

A light intensity control is provided for the reticle spot which permits the operator to follow the illumination intensity level of the main optical path. The light intensity is controlled by means of a pair of rotating light filter discs. The filter discs consist of a pair of neutral density optical filters capable of continuously changing the filter density in the light path, over the range of 2:1.

In addition, the light path must pass through a colored filter holding arrangement which switches a filter in or out of the system by means of an electric motor. This provides either a "white" reticle spot or a "red" reticle spot, at the operator's selection. It is thus possible to use a highly contrasting spot color to assist in identifying the reticle spot in the field of view.

Next in the reticle system is a zoom lens system. This remote operated zoom element adjusts, by operator selection, the diameter of the reticle spot over a range of 4:1, from the size limited by diffraction to four times larger.

The reticle spot image next passes through a second zoom lens arrangement capable of adjusting the diameter of the reticle spot over a 10:1 range. This zoom lens is operated by a servo drive which is slaved to the servo system of the movable zoom subassembly in the main optical path. Thus, as the main zoom magnification is increased, the apparent reticle size remains constant through the compensating action of the reticle zoom system subassembly.

Next in the reticle projection system is an anamorph lens assembly arranged for changing the diameter of the reticle spot on a given axis over a range of 2:1. This system is servo operated and slaved to the anamorph system in the main optical path. Thus as the anamorph system in the main optical path changes by a specific degree of expansion, the reticle system anamorph compensates by reducing the diameter of the reticle spot along the same axis of stretch.

These several systems are linked together by the various servo arrangements to better than a 1% error.

The next component in the reticle projection system is an image rotating Pechan prism. The axis of this image rotator is servo controlled and slaved from the axis of the anamorph system in the main optical path. This arrangement compensates for main optical path anamorph distortions of the reticle spot and maintains a truly round reticle spot in the field of view as seen at the eyepiece.

It will be apparent from the foregoing description of the reticle spot optical system that the possibility of off-axis deviation of the reticle spot is extremely high, considering the necessity for shape and size compensation through various optical parameter variations. In other words, unless further corrective measures were included, it could be expected that the reticle spot would move substantially off axis as the various reticle optical system elements were adjusted. This, of course, would result in measurement error since the reticle spot position would be changed with respect to the field of view.

The problem has been solved by placing a reducing afocal system in the reticle spot exit path. This system reduces the reticle spot to 1/50 of its original size before injecting it into the main optical path. This reduction of 1/50 has the effect of reducing all off-axis deviations to 1/50 of their original amount. The resulting final deviation of the reticle spot with respect to the field of view is therefore less than 1/4 of a micrometer as the reticle spot optical parameters are varied.

The Zoom Magnification System

The 10X zoom system for the main optical path is located in a vertical axis immediately above the reticle spot injection beamsplitter.

This zoom subassembly consists of five clusters of lens elements, three of them moving. Two of the moving lens elements are attached to one carriage and the other movable lens elements are attached to a second carriage. The two carriages are driven from the same cam shaft, and their position is carefully computed to place the zoom elements within the necessary accuracy for proper zoom operation. The movable lens elements slide vertically and therefore the system is mechanically loaded in one direction on the cam, and thus backlash is not a problem. The system is guided vertically with bias loaded rollers on an accurately straight shaft, and thus there is essentially no radial backlash.

The positioning cam shaft contains two variable spiral grooves machined into a long shaft. Cam followers ride in the grooves and cause the carriage elements to travel along the cam shaft spirals. The rotating cam shaft is driven with a servo system and has potentiometer readouts of position. These potentiometers provide feedback position signals to the computer which controls the entire optical system, and to the slave linkage servo arrangement which drives the reticle spot 10:1 zoom assembly and the main illumination zoom assembly.

Microswitches are arranged on the potentiometer driving gears so that the system cannot be driven beyond its maximum travel position. A brake is provided to hold the cam in its fixed position after servo movement. The servo driving motor contains an integral tachometer and an integral speed reducer.

The upper end of the zoom system carries the corner prism which turns the optical path through 90° from the vertical axis to a horizontal axis.

The Anamorph System

The anamorph system in the main optical path is for the purpose of correcting obliquity in the viewing aspect of the object. This optical system consists of four sets of prism assemblies which are placed transverse to the optical axis. The prisms are mounted on four separate rotating shafts driven from a common servo drive. The shafts are driven by precision gears which provide accurate placement of the prism assemblies with respect to each other.

A potentiometer is provided to supply a signal to the computer to show the position of the anamorph prisms. The servo motor is equipped with an integral gear reducing head and a tachometer. A brake is provided to hold the prism system stationary between operations of the servo system.

In addition to the motion of the anamorph prisms with respect to each other, the entire assembly of anamorph elements with their drives and the position readout potentiometer are rotated about their optical axis. This is done through a second set of precision gears and bearings and a servo motor system with integral gear reducer and tachometer. Readout of this position angle of the anamorph system is provided by means of precision potentiometers which supply signals to the computer and to the slave servo in the reticle projector system. A brake is arranged to hold the anamorph position fixed between servo commands with respect to the optical axis.

Since the angular position of the anamorph about the optical axis is infinite in either direction, the anamorph system is provided with electrical slip rings to supply electric power for the servo drives and the signal feedback system on the anamorph prism positioning system. These slip rings are of the low-noise, low-speed variety and are not especially complicated.

The Image Rotating System

After passing through the anamorph system, the main optical path passes through a Pechan prism image rotating system. The prism is carried on precision bearings and is driven through precision gears by a servo motor with integral gear reducer and tachometer. A brake holds the system in position when the servo system is not in operation. Precision potentiometers are provided to supply signals to the computer which show the position of the image rotator.

The purpose of the image rotator is to orient the left eye and right eye fields of view with respect to each other so that proper stereo fusion is possible. Stereo fusion is attained through the elimination of Y-direction parallax in the two fields of view, and this situation is realized through the proper orientation and position of the pair of images in the fields of view.

The Eyepiece Switching System

The eyepiece assembly is the point at which the right and left eye channels come together for presentation to the operator for stereo viewing. The previous descriptions of the optical system have described specifically only the one eye channel; however, there are two complete systems, one for each eye, identical to the one system that has been described.

The light level at the eyepieces is under operator control without affecting the main optical system light level or the level of illumination at the scanning phototubes. For this purpose, two light level control filter discs with a transmission range of 5:1 are provided.

One of the requirements of the Stereocomparator instrument is that it be capable of viewing through a film of density 3.0. This means that the light reaching the operator's eyes has to be controlled to limit accidental excessive brightness. Thus, if a hole or zero density patch in a film of 3.0 density were to be suddenly moved into the field of view, the light level would be increased by a factor of 1000. While there would be no possibility of permanent damage to the operator's eyes, nevertheless it was considered that this increase in the illumination level would be a source of discomfort to the operator and would be highly objectionable.

The light level control phototube provides a means of measuring the average light level and includes the capability of sensing sudden high light level fluctuations. However, the light level control filter disc device contained in the main illumination system would not respond rapidly enough to prevent discomfort for the operator. The problem was solved by providing a pair of opaque shutters in the main optical path at the eyepieces, controlled by the photomultiplier light level control phototube.

These shutters have a 1 millisecond response time in shutting off excessive light from the operator's eyes. In addition, the opaque shutter system is so arranged that when the illumination level returns to a normal value the shutters will automatically move out of the optical path and the operator may again see the fields of view.

The eyepiece assembly is provided with a means of switching the eyepieces relative to the field of view; that is, the two eyepieces may be switched so that both look at either the right eye channel or the left eye channel. Additionally the eyepieces may be switched so that each eye sees its respective channel or so that the right eye sees the left eye channel and the left eye sees the right eye channel. This system flexibility is provided by a series of prisms mounted on a rotating disc assembly which cause the various optical switching arrangements described above to be performed.

Provision is included in the eyepiece assembly for adjustment of interpupillary distance, for vertical angular adjustment and for horizontal angular adjustment between the two eyepieces. Thus, the so-called "squint angle" can be accommodated by the vertical adjustment, while the horizontal adjustment is provided primarily to eliminate operator eye fatigue in conjunction with the adjustment of interpupillary distance.

Scanning and Light Level Control

The Stereocomparator optical system contains two automatic image plane scanning features. These consist of a photomultiplier tube which maintains the illumination level at a constant average value by adjustment of the main illumination system, and an image dissector phototube which scans the field of view and produces a specially shaped variable raster whose output controls the computer and automatically maintains stereo fusion for the operator through servo adjustment of the optical system.

A beamsplitting prism assembly is provided immediately after the image rotator in the main optical path to provide images for these two phototube systems. A second beamsplitting prism splits the secondary ray into two separate rays. The beam which supplies illumination to the light level control photomultiplier tube is diffused to produce an average level of illumination. The phototube measures the light level and uses the information to operate a servo link which controls the adjustable filter discs in the main illumination system.

The second phototube beam is focussed on the photocathode of a high sensitivity image dissector phototube which then scans the field of view in a precisely controlled pattern. The output from the left eye field of view image dissector tube is compared with the output from the right eye field of view image dissector tube. These comparative outputs are analyzed in a special electronic computation system called an image analyzer which then produces a series of control signals to the computer. The computer thereupon provides necessary and appropriate commands to the various elements of the main optical system which in turn make the various servo operated optical adjustments that create stereo fusion for the operator.

Thus within the corrective capability of the optical system, the fields ov view of the right and left eye channels are automatically corrected for scale, skew and orientation differences as a means of maintaining proper stereo fusion for the operator.

The Film Drive and Platen

The Stereocomparator is designed to use roll film up to ten inches in width carried on 500 foot film reels. The glass film platen is 10" wide by 20" long and is mounted between the film reels. Immediately below the platen and adjacent to the operator, "cold" light tables are mounted for overall direct scanning. This allows the operator to select and position the desired film frame area in a convenient manner prior to detailed viewing or measuring. The film drives are servo controlled and provide a uniform film tension with a speed of travel of up to 350 feet per minute in either direction.

A vacuum film clamping arrangement is provided which self-seals both ends of the platen and along both edges of the film. The edge seals also serve as film guides during motion of the film. They are mounted on a positioning device to adapt the seals to varying widths of film. The vacuum system seals the film tightly against the platen in about 5 seconds.

The Stages and Guides

The film platens are installed on a granite stage which is guided for x and y coordinate motions by a granite "Tee" assembly. The guiding surfaces are granite against anodized aluminum air bearing pads.

A granite base block approximately 5 feet wide by 7 feet long by 1-1/2 feet thick and flat to within 50 millionths of an inch supports the movable stage assembly on air bearings.

The air bearings are of the load compensated variety. This is required to minimize the effects of film transfer between reels at the platen. If the platen were to tilt under the change of weight distribution then frequent refocussing of the objectives could become an operating problem.

Granite is used as a stage and base material for several reasons. The primary reason is based on the dimensional and shape stability of granite as a structural material. The granite is completely stabilized and does not warp or otherwise deform with time. In addition, it is stable to changes in temperature as the large mass used for the Stereocomparator is not affected by short time temperature oscillations.

The fact that the granite arrangement results in a heavy assembly is advantageous for the vibration absorption equipment. That is, external vibrations are more easily damped out.

The Laser Interferometers

The high precision measuring accuracy for the stage position is realized through the use of laser light and a Twyman Green interferometer. There are two laser units used, one for each of the measuring stages.

The output of each of the Helium-Neon lasers is split into two beams, one provided for each of the x and y measuring axes. The two beams are directed to a pair of interferometers - one for the x and one for the y axis. The interferometers include long mirror reflectors, whereby the interferometer readout photocells are installed directly opposite the objective lenses and perpendicular to the x and y axes respectively. By locating the interferometers centrally with respect to the objective lenses, the effects of misalignment of the stages during motion is minimized.

The output of the interferometer light is in the form of light and dark bands. The direction of motion of the light bands across the face of the photoelectric field effect transistor pickup cells which comprise the receptor system of the interferometer, determines the direction of stage motion. Thus by proper arrangement of phase analysis equipment, the counting system can be directed to count up or count down correctly.

It is apparent that counting interference fringes from He-Ne laser light results in a very unhandy unit of measurement. Therefore a special purpose computation counter was provided to transform the interferometer counts into 0.1 parts of a micrometer. These counting devices read out digitally directly in micrometers and tenths of a micrometer for optimum operator and computer convenience. The least count of the system is thus 0.1 micrometers and the counting registers record counts over the full 10 by 20 inches of travel of the stage, as the stages are moved about by the operator or through the computer control.

The interferometers thus record exactly the position of the stages with respect to their starting position and with respect to each other. This numerical information is transmitted to the computer or to the card punch or to other equipment, as desired, by means of appropriate logic.

The Structural Supports

There are two complete three-piece granite stage assemblies in the Stereocomparator system, one for each of the two eye channels.

The two granite base slabs are supported on a strong and rigid U-shaped structural steel frame. Each granite base slab is supported by a 3-point suspension from the steel frame. In order to maintain one of the granite bases level with respect to the other granite base, the structural steel frame is supported by four pneumatic combination level supports and vibration absorbers. These units absorb vibration down to almost one Hertz and will maintain the overall system level to within a few millionths of an inch. The two granite base blocks not only support the stages but also provide a rigid mounting for the optical system.

The Optical Bridge

The optical bridge which carries the entire optical assembly is in three sections. The two outboard sections are supported by the base granite while the center section carrying the eyepieces is supported from the structural steel frame which supports the granite slabs.

This three-piece optical bridge was designed so that the optical system is not dependent on the absolute position of the granite base blocks with respect to each other. Some movement of these granite blocks is allowable and has no effect on the measuring accuracy of the system since the granite blocks also carry the Twyman Green interferometer and the laser system.

The center portion of the optical bridge supports the eyepieces and the various subassemblies of the optical system which occur in the collimated light region of the main optical path. Thus relative movement between each of the eye channels in this portion of the optical system does not result in changes to the measuring accuracy since the relation between the reticle spot and the field of view is unchanged.

The Ancillary Equipment

The electronic equipment for driving the servo motors, for reading out stage positions for the computer, and for performing the numerous subsidiary tasks of the Stereocomparator are housed in three double electronic racks approximately seven feet high. An additional double rack of similar size is provided to house the controls and the special compressed air distribution equipment for supplying air to the air bearings on the granite stages. Additionally this cabinet contains the controls for the platen vacuum film holddown system, electric power control and the electrical distribution systems.

A teletypewriter is included in the Stereocomparator system for the purpose of transmitting computational data into the computer and for communicating special instructions to the computer for requirements such as stage x-y prepositioning coordinates.

A card punch and reader is also provided as part of the system in order to provide a card record of data at times when other on-line data acquisition equipment is not available.

METHOD OF OPERATION OF THE STEREOCOMPARATOR

In general, photogrammetry has developed over the years with cartography as its prime objective. The Stereocomparator is firmly not a map-making tool. It is a mensuration device for determining, through a computer, dimensional parameters and other special information for selected viewing points in transparent imagery. The use of the instrument is not limited to simple stereo photography of terrain since the inherent flexibility of the equipment and its variety of operating modes result in many different applications.

In the case of stereo type terrain photographs, the Ultra High Precision Stereocomparator automatically provides a stereo view from a pair of geometrically similar, or even partially dissimilar, stereo photographs. These photographs must be in the form of film transparencies, either negative or positive. The optical system for the instrument contains two identical optical paths for viewing the two transparencies. Each eye is thus provided with a means of optically transforming the two different photographic views to make them compatible for stereo viewing.

The variable optical elements of the two optical systems are operated through servo motors controlled through a computer and an electronic scanning system. The views are thus transformed by the optical system and presented to the left and right eyes of the operator in the form of a stereo pair. The instrument is limited by the optical parameters, to the degree of optical correction it can perform. That is, it can only operate successfully with imagery that reasonably approaches the criteria for a stereo pair of photographs.

The Stereocomparator can be considered fully flexible for all different types of photography, provided an appropriate mathematical program can be written for the computer. At present, programs for pan, strip and frame photography are available.

In addition to limitations from the parameters of the optical components, there is a further limitation in that not all of the true optical transformations have been provided in the instrument. For example, the instrument does not include a means of varying the scale as a function of position in the field of view. That is, the scale of the field of view may be changed as a whole, but not selectively with position in the field. Because of this limitation, stereo fusion may not be attainable over the entire field of view.

We are told that a 12 degree included angle at the eye contains all the information necessary for the eyes to maintain a state of stereo fusion. The actual field of view of the instrument is 40 degrees at the eye. This merely means that for photographs substantially deviating from a stereo pair then true stereo viewing may only be achieved over the central 1/3 of the field of view.

This difficulty is not particularly significant since the Stereocomparator is primarily a mensuration instrument equipped with a reticle spot at the center of its field of view. Thus the requirements for stereo fusion and mensuration are compatible at the center of the field of view and the theoretical failure of the instrument to provide wide angle optical transformations to provide true stereo fusion do not significantly affect the use, accuracy or operation of the instrument.

The general historical background of the Stereocomparator has been pointed out and the design of the other various pieces of equipment comprising the system has been described. In addition, the arrangement of the optical system was considered in some detail, and thus having treated the subsystems, the Stereocomparator system as a whole will be examined.

The Stereocomparator has three primary modes of operation: (a) manual, (b) computer operated, and (c) computer operated with image analysis (i.e., with correlation). These modes differ in many respects:

(a) The manual mode provides the operator with controls by which he can adjust the optics and move the stages to suit his needs. He can thus traverse the field of view and produce stereo fusion in a stereo pair of photographs and make measurements as required of the x, y and z axis.

There is a sub-mode associated with the manual mode which utilizes the computer program to assist the operator in the orientation of the various controls of the machine. This in no way obviates the operator in the adjustments of the controls, but it is of substantial assistance when making the adjustments to have the computer direct the adjustments to the proper control element with the proper motion. For example, the photography in the field of view may present the subject in an upside down position which the operator can correct by rotating his image rotation elements. Thus the image would appear in the proper position for viewing. However, in order to make the field of view appear to travel upwards in the eyepieces, the operator would have to traverse the stages in a direction which would normally cause the images to go downwards in the eyepieces. By the time the anamorph and the zoom functions for both eyes in a stereo operation are manually compensated, the advantage of having the computer perform the proper orientation for the operator becomes immediately obvious.

(b) The computer controlled mode can be described as semi-automatic in that the operator performs certain key functions with respect to updating the computer parameters. In this mode the computer program with the proper numerical parameters and computations is inserted into the computer. The program considers the geometrical parameters of the stereo pair of photographs being viewed, including the special characteristics of the camera equipment and distortions and deviations present in the finished film. If all the parameters were exactly and absolutely known, it would theoretically be possible to scan large photographs and automatically maintain stereo fusion for the operator.

In practice, this is not possible. There are enough uncertainties so that the computer cannot be exactly programmed. Further, the amount of computation necessary to maintain an exact program is probably beyond the capability of any but the most elaborate computing equipment. Therefore, while this could presumably be considered a desirable goal, it cannot presently be attained practically.

In order to take care of this lack of information condition, the Stereocomparator is so arranged that the parameters for the program are continuously being upgraded. The operator performs this function by adjusting the various optical and stage position controls for optimum stereo-viewing conditions. The computer is arranged to sense this change in parameters, or coefficients, and to perform additional computations which utilize the operator's adjustment of the controls in order to establish the most accurate basis for interpolation and extrapolation. This means that the operator can not only measure accurately over a small area under full computer control, but can then scan along greater distances by performing manual adjustments as required. Thus, when the operator sees the stereo image begin to fail, the stereo fusion can be recovered by the operator controls and the machine either used for measurement again in the computer corrected small area or else the operator may continue the scanning operation under updated computer control.

One point that becomes apparent is that unless the majority of the mathematical parameters are known concerning a particular pair of photographs, the computer mode of operation alone does not maintain stereo fusion and the extent of operator participation necessary for upgrading the computer becomes too great a burden. Further, the initial adjustments for stereo viewing must be performed by the operator since the Stereocomparator has no provision for identifying the absolute position parameters in a given pair of photographs.

Prepositioning is provided in the system as a further aid in the computer control mode. For prepositioning it is necessary for the operator to place a grid over each of the photographs, and establish by grid coordinates a series of up to six points of interest. These grid coordinates may then be typewritten into the computer memory by the operator's teletype. Then, when the photographs are placed on the platen of the Stereocomparator and the prepositioning controls are operated, the computer will drive the stages to these various preselected positions.

(c) An additional mode consisting of computer control plus automatic correlation is provided for maximum operating convenience. In this mode, a pair of image dissector phototubes are used to scan the same fields of view that are presented to the operator's eyes. The output from these tubes supplies electronic information to the servo drives utilizing a special purpose computer called an image analyzer or correlator. This special computer performs various mathematical calculations whose output determines the geometry of the raster for the scanning of the image dissector tubes and additionally supplies optical and stage position data to the computer. The computer then readjusts the Stereocomparator optical-mechanical servo systems which cause the scanning geometry of the raster to return to an arbitrary condition. This normal raster condition is defined as that which produces stereo fusion.

An image dissector scanning system of this type has a relatively limited pull-in range, and additionally the computer must perform many computations for each stage position or optical system change. The film images must be within about five percent deviation from the stereo fusion condition before the image analysis equipment can be effective.

It is clear that the addition of the image analyzer to the computer control mode is of tremendous advantage to the operator from the point of view of convenience, time saving and eye fatigue. It is thus not necessary that all the parameters be known for the photographic system and the operator is required only to perform initial adjustment for stereo fusion to about 95 percent accuracy.

SUMMARY

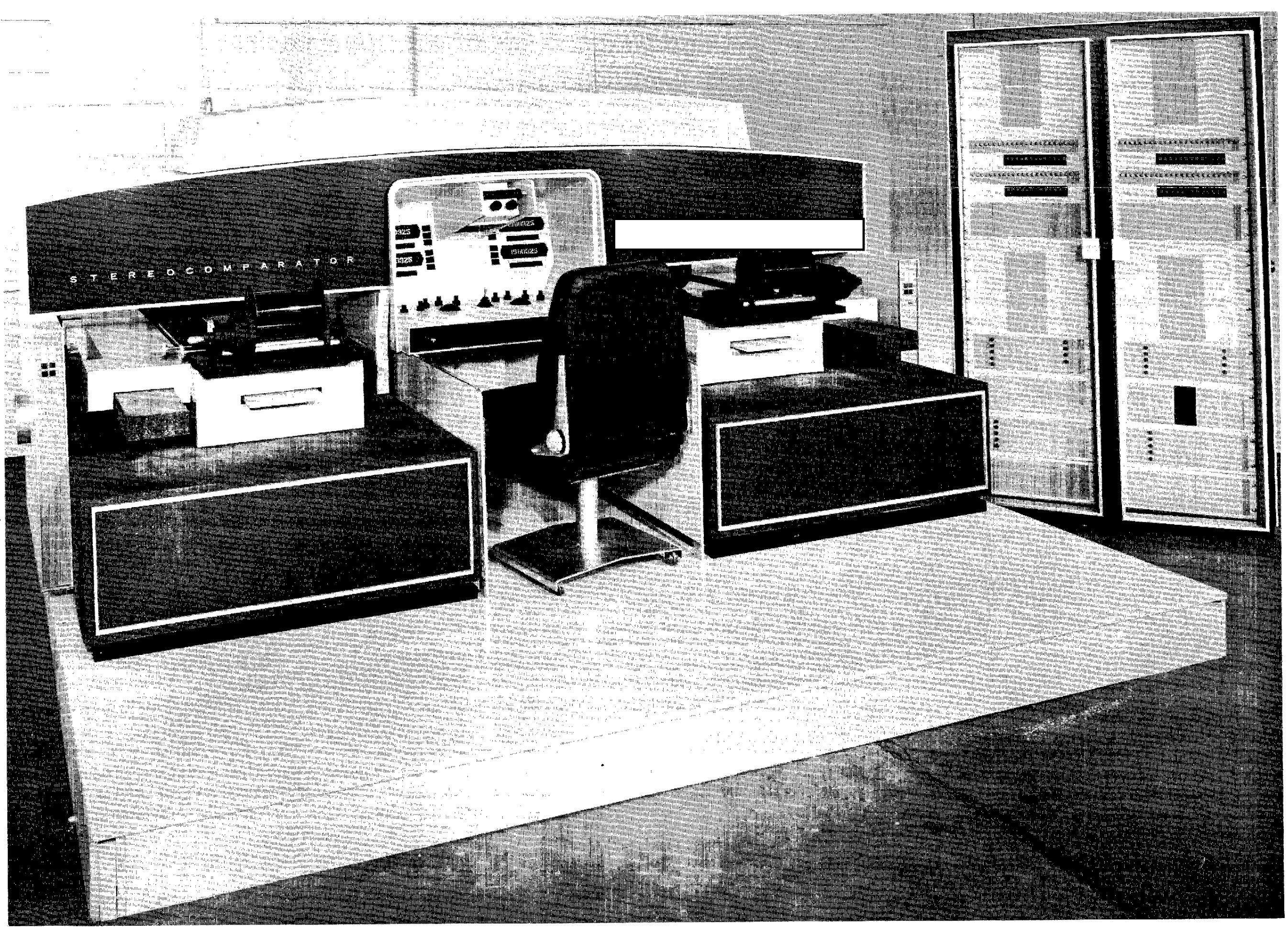
From the foregoing discussion, it is apparent that the primary purpose of the Stereocomparator is to enable an operator to rapidly and accurately scan and measure stereo photographs, over a wide range of film and acquisition parameters.

The time previously necessary for an operator to adjust and optically correct for stereo fusion has been reduced from many minutes to fractions of a second, and thus the productive output of measurements using the Ultra High Precision Stereocomparator is vastly greater than lesser instruments not equipped with its automatic features.

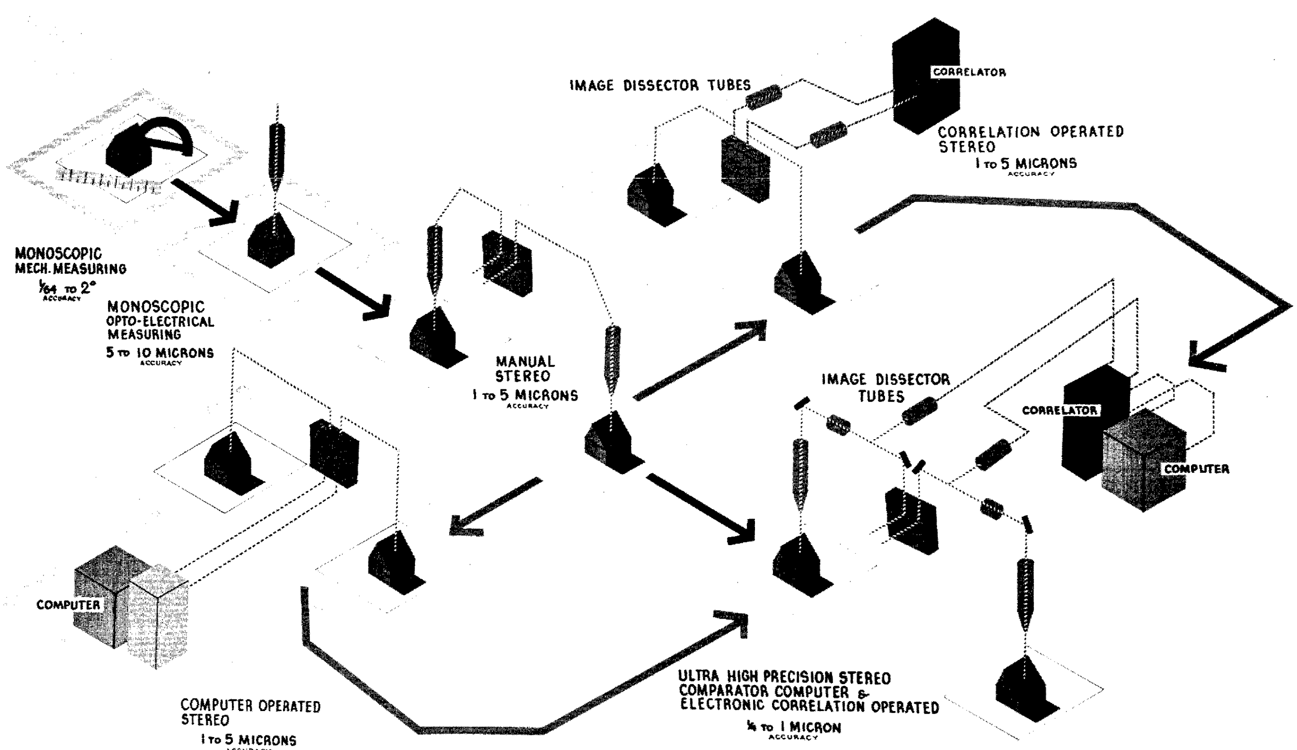
All controls are placed conveniently in front of the operator in a control console. Above the control console are the eyepieces, and on each side are the two film stages. The operator is thus in the most convenient position for viewing and control of the Stereocomparator.

The instrument is equipped for precise mensuration with a least count of 0.1 micrometer and with an overall accuracy of one part in 100,000 plus one quarter of a micrometer.

The science of photogrammetry has been advanced substantially by the availability of the Ultra High Precision Stereocomparator.

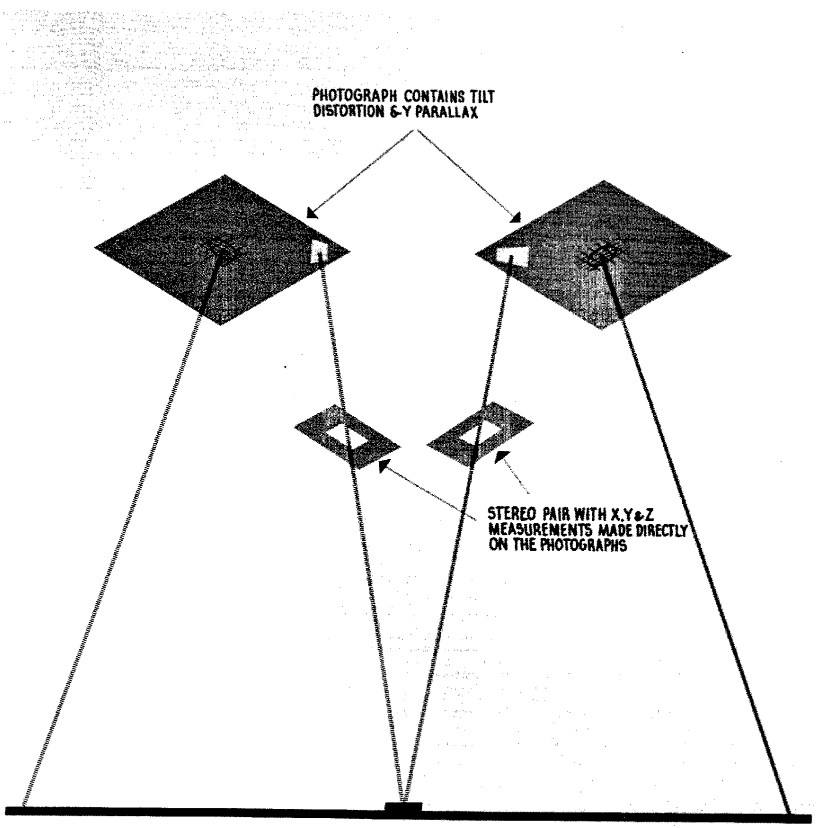


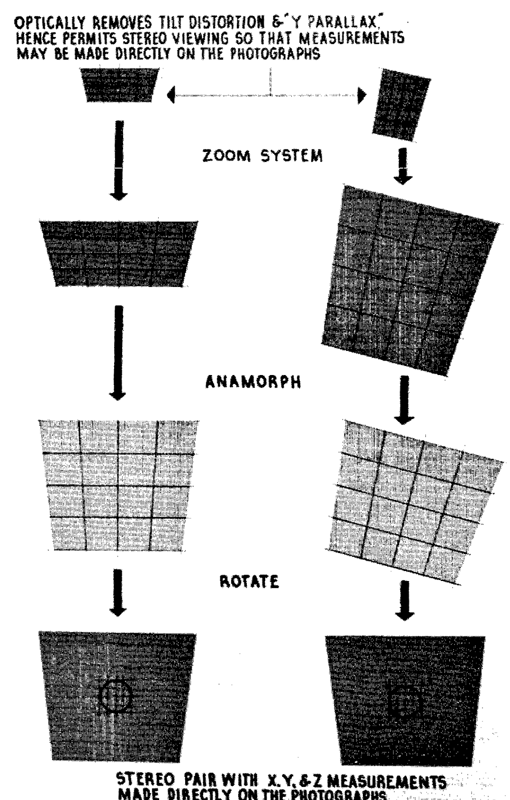
25X1



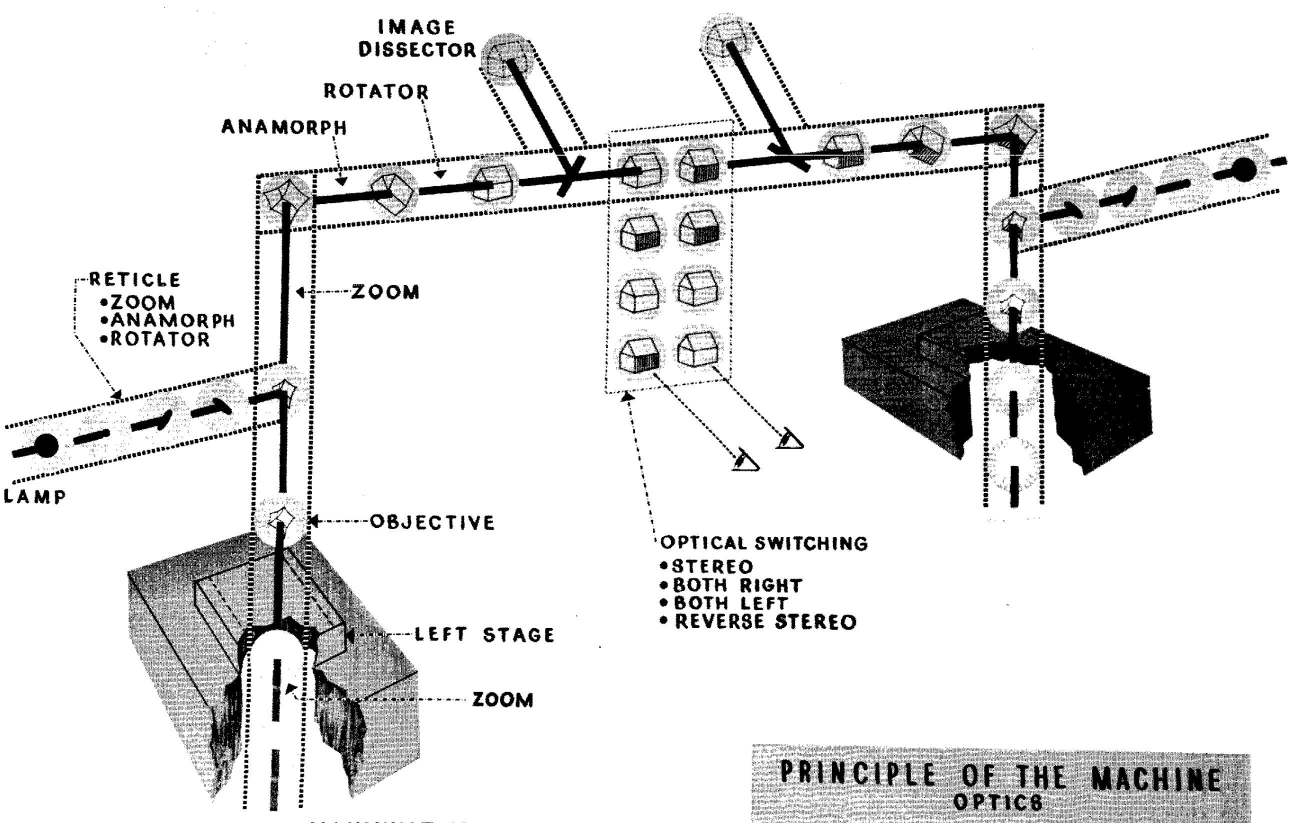
EVOLUTION OF THE ULTRA HIGH PRECISION STEREO COMPARATOR

ULTRA HIGH PRECISION STEREOCOMPARATOR

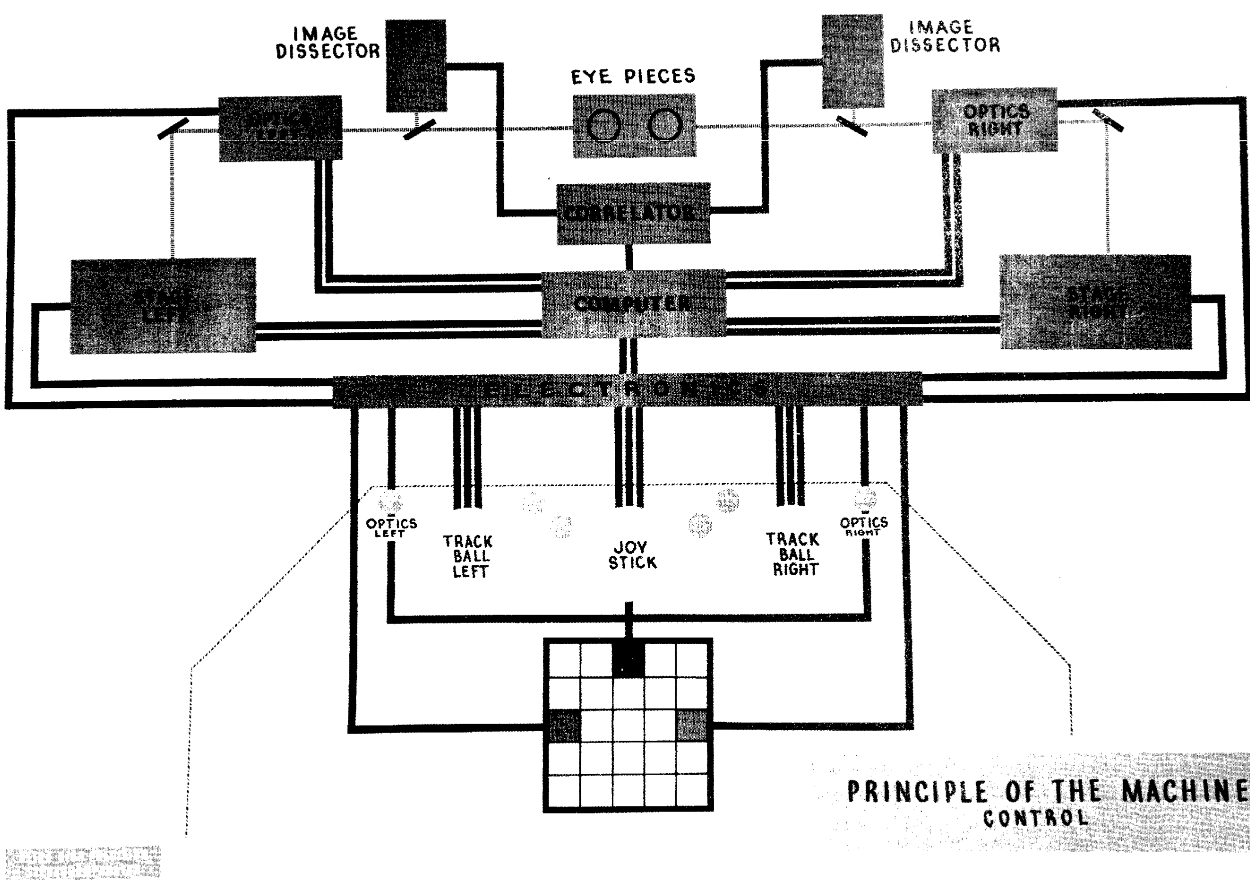




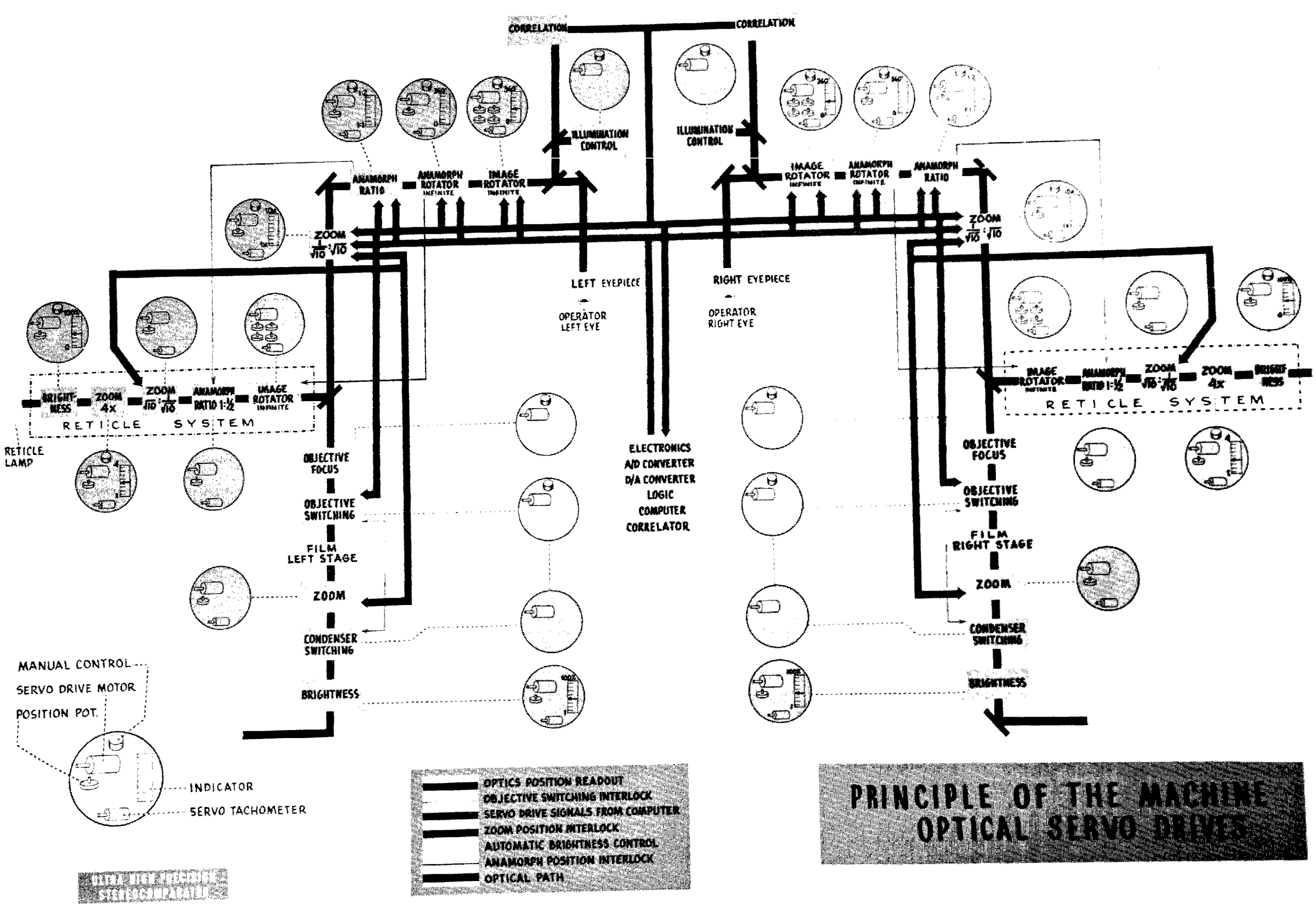
OPTICAL TRANSFORMATIONS

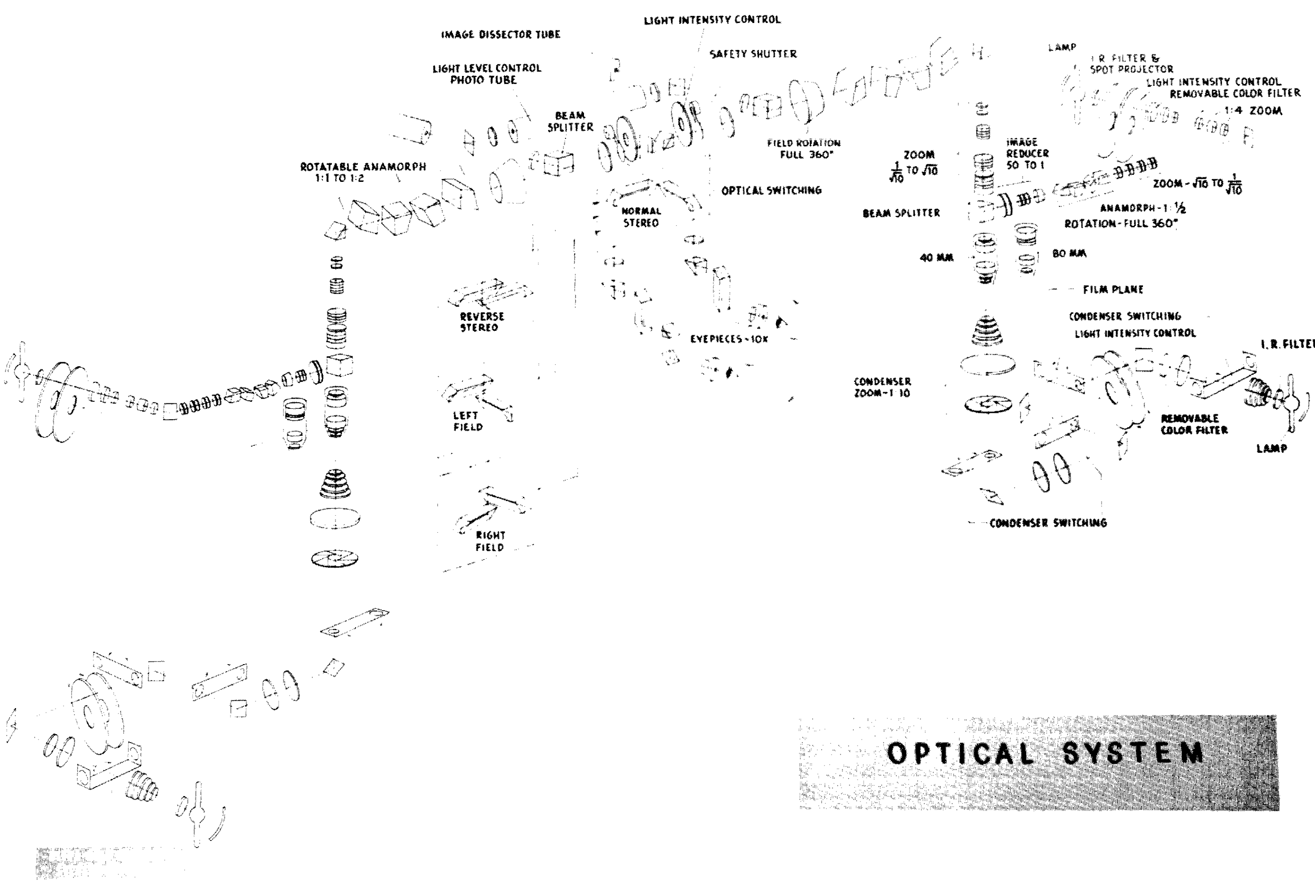


PRINCIPLE OF THE MACHINE
OPTICS



PRINCIPLE OF THE MACHINE
CONTROL


CORRELATION
CORRELATION
ILLUMINATION CONTROL
ILLUMINATION CONTROL
ANAMORPH RATIO
ANAMORPH ROTATOR INFINITE
IMAGE ROTATOR INFINITE
IMAGE ROTATOR INFINITE
ANAMORPH ROTATOR INFINITE
ANAMORPH RATIO
ZOOM
ZOOM
LEFT EYEPIECE
OPERATOR LEFT EYE
RIGHT EYEPIECE
OPERATOR RIGHT EYE
BRIGHTNESS
ZOOM 4x
ZOOM
ANAMORPH RATIO 1-½
IMAGE ROTATOR INFINITE
RETICLE SYSTEM
RETICLE LAMP
IMAGE ROTATOR INFINITE
ANAMORPH RATIO 1-½
ZOOM
ZOOM 4x
BRIGHTNESS
RETICLE SYSTEM
OBJECTIVE FOCUS
OBJECTIVE SWITCHING
FILM LEFT STAGE
ZOOM
CONDENSER SWITCHING
BRIGHTNESS
ELECTRONICS
A/D CONVERTER
D/A CONVERTER
LOGIC
COMPUTER
CORRELATOR
OBJECTIVE FOCUS
OBJECTIVE SWITCHING
FILM RIGHT STAGE
ZOOM
CONDENSER SWITCHING
BRIGHTNESS
MANUAL CONTROL
SERVO DRIVE MOTOR
POSITION POT.
INDICATOR
SERVO TACHOMETER
OPTICS POSITION READOUT
OBJECTIVE SWITCHING INTERLOCK
SERVO DRIVE SIGNALS FROM COMPUTER
ZOOM POSITION INTERLOCK
AUTOMATIC BRIGHTNESS CONTROL
ANAMORPH POSITION INTERLOCK
OPTICAL PATH
PRINCIPLE OF THE MACHINE
OPTICAL SERVO DRIVES



OPTICAL SYSTEM